Theme session Q

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Sustainability thresholds and ecosystem functioning: the Selection, calculation, and use of reference points in fishery management

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Fishery management systems worldwide rely on defining biological reference points, which serve as a basis for setting limits and targets to fishing intensity (e.g., catch and bycatch) and population sizes (e.g., stock biomass). These are important management quantities that govern the establishment of harvest specifications and are used to determine whether a stock's biomass is too low (overfished) and whether fishing intensity is too high (overfishing occurring). In addition, biological reference points can be critical for establishing harvest control rules and management procedures that enact pre-specified policy measures when excessive harvests or depleted biomass occur relative to reference levels. Despite fisheries management being fundamentally reliant on reference points, there are challenges and uncertainties surrounding the choice and calculation of reference points, such as whether to use single or multi-species maximum sustainable yield (MSY) or proxies, and related to the various applications of reference points used in a management/policy context (e.g., at the national or multinational level) to achieve sustainable fisheries and other desired management objectives. For instance, equilibrium population assumptions underlying the calculation of many reference points are challenged by spatial and temporal variation due to density-dependent mechanisms (e.g., recruitment, individual growth, maturity, and mortality), climate change, variable management and fishing practices, predator-prey dynamics, and myriad other factors. The reliability and robustness of equilibrium-based (static) reference points in the presence of regime shifts may be limited, and it remains uncertain how best to incorporate such directional changes into stock management plans.

Multispecies and ecosystem-level reference points often provide a different view of species-specific sustainable harvest levels, because single species approaches do not account for the various trade-offs and uses at the broader system level. For example, single species FMSY management paradigms form the basis of policy advice provided by ICES (and many countries worldwide), but these typically ignore important aspects of ecosystem functioning (e.g., carrying capacity, density dependent population dynamics, and species interactions). Ignoring ecosystem dynamics often leads to inconsistent estimates of FMSY when considering a single-species perspective relative to a system-wide or multi-species approach and can impede stock rebuilding initiatives, particularly in multi-species fisheries. There has been increasing exploration of ecosystem dynamics and indicators that could be utilized as part of a more holistic approach to integrated ecosystem assessment. The scientific basis for fishery management decisions in the coming years must be robust or adaptable to changing environments and complexities of multi-sector resource utilization across a variety of competing stakeholder objectives.

This session offered a forum to explore best practices and new approaches to selecting, calculating, and using reference points in fishery management. The importance of reference points in fisheries research was represented by the over 50 submissions to the symposium. Presentations were divided into three sessions, which represented the major fronts for development of biological reference points (single species versus ecosystem approaches) and how they are used (management implications). Within each session, topics tended to revolve around central themes. For the single species session, focus was on how to adapt relatively simple dynamic pool models to account for non-stationarity in parameters whether due to climate-change, spatial dynamics, or density-dependent effects. The ecosystem session explored how to model multispecies and ecosystem dynamics, while dealing with institutional inertia caused by reluctance to adapt new and often complex methods for defining sustainable harvest rates. The management session demonstrated how harvest control rules (HCRs) utilizing single-species, multi-species, and ecosystem reference points performed for providing robust management advice. Although the approaches for defining and selecting reference points differed widely among presentations, many commonalities were noted that permeated across the sessions and topics.

Not surprisingly, given their role in defining HCRs and management actions, biological reference point modeling is a burgeoning field. However, the growth of the field across many different research fronts has led to a lack of cohesion or agreement among a variety of approaches and methods. Unfortunately, the choice of approach can have a large impact on stock status determination and resultant catch recommendations. Additionally, reference points have different significance across regional management systems (i.e., in the EU, non-EU European countries, US, Canada, and other areas), which has had an impact on the approach taken for development and use of reference points in each region. Therefore, it is imperative that an attempt is made in the near future to document the array of approaches and frameworks currently available, and, eventually, to provide guidance and recommendations on how and when to use various aspects of each (e.g., when is it necessary to account for time-varying productivity or density-dependence in population parameters).

The ultimate conundrum that must be addressed when defining reference points is how to account for ecosystem interactions. Perhaps the most robust conclusion that can be made from this session regarding research on biological reference points is that ecosystem and multispecies interactions should not be ignored when trying to define sustainable use of a marine resource. Whether a single-species or multi-species approach was taken, novel research topics tended to focus on how to account for spatiotemporal environmental impacts. Within the single-species context, dynamic virgin biomass (B0) and time-varying productivity models appear to be gaining traction, which often have implied ecosystem considerations. Alternate approaches that account for density-dependent processes (e.g., growth, mortality, maturity, and recruitment; all of which have been shown to be prevalent in ICES stocks) may provide a step towards accounting for multi-species and ecosystem interactions without requiring full-scale multi-species models. Additionally, these approaches can be utilized in the near-term as a first step towards developing operational ecosystem-level reference points. Every presentation in the single-species session investigated how to account for environmental impacts when calculating reference points, indicating that researchers around the world appreciate the influence these impacts can have on isolated single-species harvest recommendations.

The symposium highlighted that there is no longer a clear distinction between single-species and ecosystem approaches to defining reference points. The critical issue moving forward is no longer whether ecosystem considerations need to be accounted for in setting harvest limits, but how to mesh the approaches of single-species models that incorporate ecosystem considerations with those of multi-species ecosystem models. The former represent the basis of most stock assessment frameworks used for management advice, but the latter demonstrate the most promise for identifying ecosystem level limits and thresholds. One potential way forward is to develop ecosystem overfishing measures to provide a system level cap on fishing pressure, but then use single-species models that account for ecosystem considerations to determine stock status indicators to develop operational advice.

A potentially powerful tool that could be used to explore how outputs (e.g., estimates of multi-species MSY and FMSY) differ across modeling frameworks is ensemble modeling. Although ensemble modeling is typically used to develop management advice averaged across various models that represent plausible states of nature within a single-species context, the approach might be useful to compare models across frameworks (i.e., single-species and ecosystem) to determine which assumptions drive differences in outputs. Using ensemble modeling in this way could improve individual models by highlighting important ecosystem considerations and other common factors that appear to be most strongly driving biological dynamics, and, thus, should be considered for inclusion in a given model. As with any new tool or approach, caution is warranted because multiple methods that provide similar outputs do not imply that a given result or assumption is necessarily correct or appropriate. Further research with ensemble modeling would be beneficial to explore this potentially unique avenue for melding results from single-species and multi-species reference point frameworks.

Crossing the science-management interface is one of the biggest difficulties with developing reference points and providing catch advice to managers. Developing stock status indicators is a scientific question, but determining risk levels is a management decision. Managers often want advice on the risk of overfishing, but providing such advice in an objective way is challenging and is only magnified when dealing with tradeoffs among species in a multi-species context. Probably the largest hurdle with developing single-species management advice based on ecosystem overfishing limits is determining which species need to be carefully managed and monitored while concomitantly determining those that should be allowed to be fished harder (i.e., potentially above their single-species MSY), thereby inherently being more risk prone for some species over others. There is now a strong body of research that indicates not all species can or should be maintained at their single species BMSY levels. The question then becomes how do scientists determine the 'optimal' balance of species from an ecosystem perspective, and should management on a species by species basis eventually be phased out? If a healthy, well-managed ecosystem requires maintaining a balance and diversity of species across ecological niches, then developing ecosystem reference point models that account for species diversity and ecosystem functioning should be a priority. Developing models and simulation frameworks to investigate these types of questions and policy issues is likely to continue as a prominent frontier of fisheries research.

Accounting for ecosystem interactions within single-species reference point models is becoming widespread and has shown promise as an intermediate step towards complex and data intensive multi-species ecosystem models. Although ecosystem overfishing limits are likely needed to stem systemic depletion of species, management bodies are often ill-prepared or lack clear avenues to use or implement this type of system level information or multi-species advice, and institutional inertia may preclude or delay incorporating these concepts into applied management. In the near-term, accounting for ecosystem dynamics through application of single-species reference point models that assume dynamic B0, time-varying productivity, or density-dependence in important population parameters may provide an intermediate step towards inclusion of ecosystem considerations into (multi-species) model outputs used for management advice. However, given that these methods may provide wide-ranging results, and may be equally justifiable in a given scenario, additional research is needed to determine if a single approach is appropriate for a given scenario, or if a combination of methods should be used. Ultimately, multi-scale approaches to reference points may demonstrate the most promise wherein ecosystem level overfishing limits provide an overall cap to harvest levels, but single-species models (embedded with ecosystem considerations) are utilized to provide management advice for heavily utilized or keystone species. As fisheries management moves towards ecosystem reference points, further research will also be needed on the optimal balance of species within the ecosystem (e.g., diversity across ecological niches) and how to best develop single-species catch advice within a systems-level ecosystem-based management framework.